CHARACTERIZING THE LUNAR PARTICULATE ATMOSPHERE WITH THE AUTONOMOUS LUNAR DUST OBSERVER (ALDO)

Dr. C. J. Grund, Ball Aerospace & Technologies Corp.
and
Dr. J. E. Colwell, Physics Dept., University of Central Florida

Presented by: Chris Grund
cgrund@ball.com, 303-939-7217

NLSI Lunar Science Conference
NASA Ames Conference Center, Moffett Field, CA
7/21/2008

Motivations for ALDO:

- **Systematically study lunar dust “weather” phenomena**
- **Monitor and characterize anthropogenic effects on the dust environment**
- **Observe micrometeorite/regolith interaction processes**

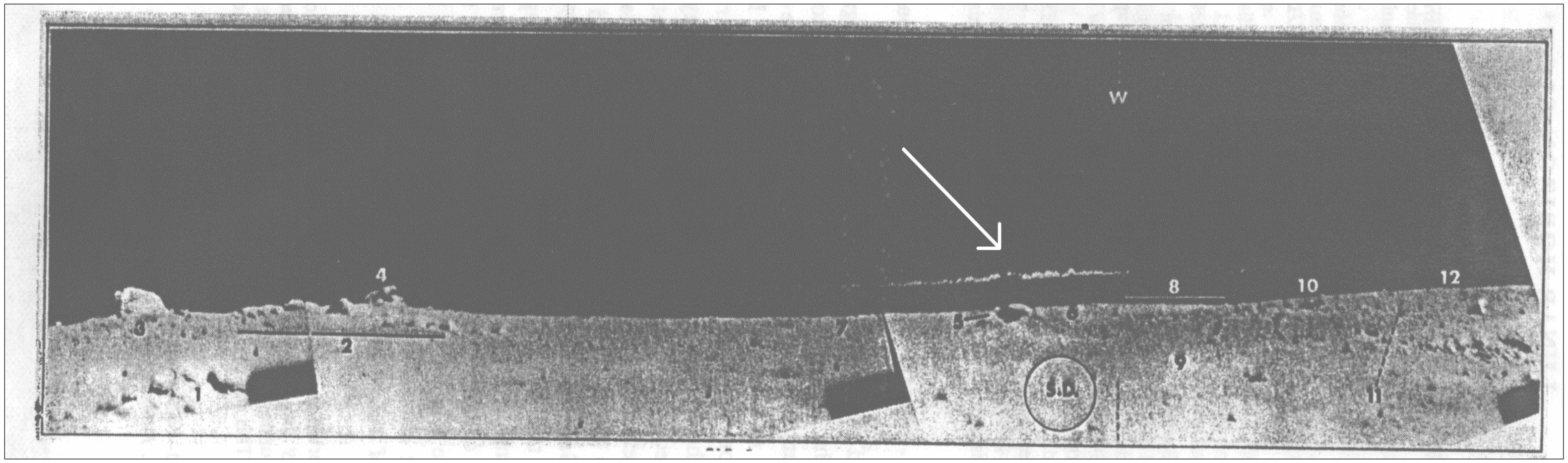
ALDO is:

a sensitive, short wavelength scanning laser radar (lidar).

Acknowledgements:

Feasibility and architecture study supported by NASA LSSO contract NNN08CC16C

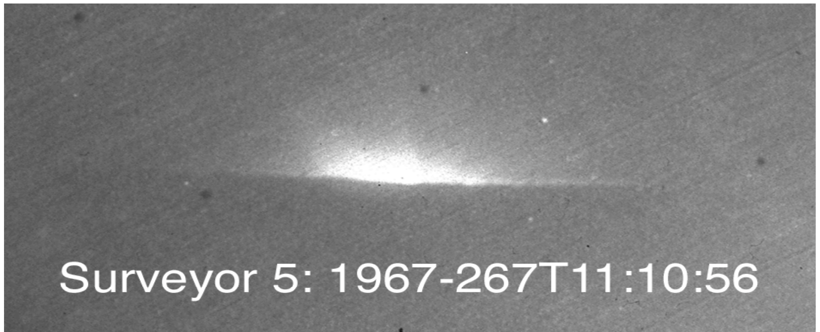
Evidence for a Lunar Dust "Atmosphere"
Horizon Glow

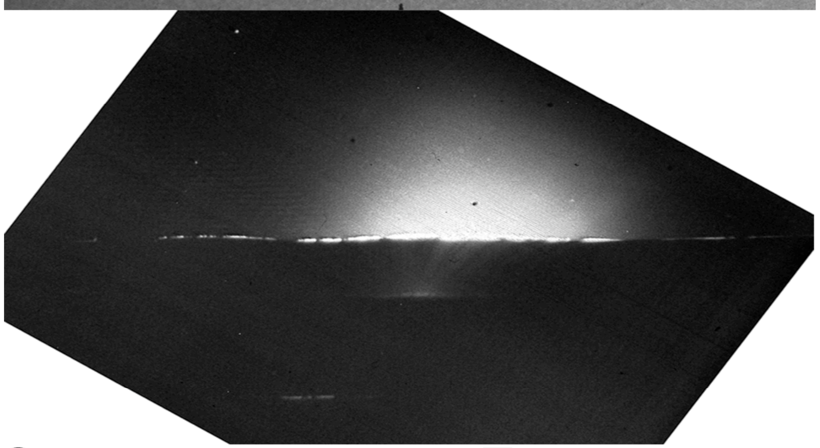


Rennilson and Criswell (1974): Analysis of Surveyor lander images of horizon glow after sunset.

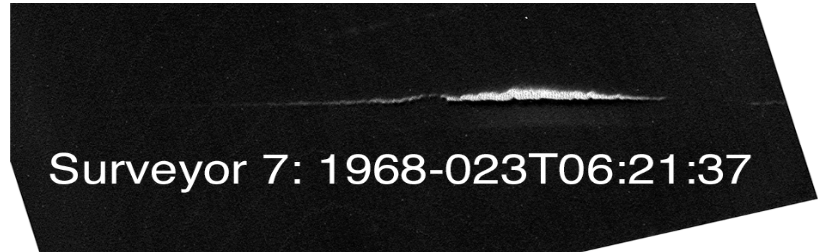
- Image is a composite
- dust cloud has been repositioned
- distance to horizon ~ 150 m suggests h~0.3 m
- angular extent suggests particle radii ~6μm (fwd scatter peak)

Lunar Horizon Glow - 2

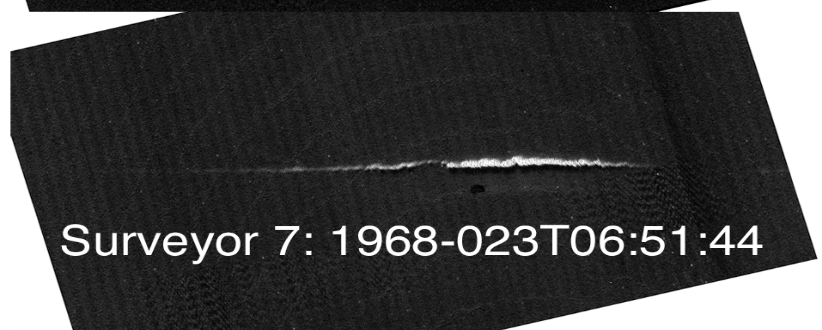

Surveyor 5: 1967-267T11:10:56

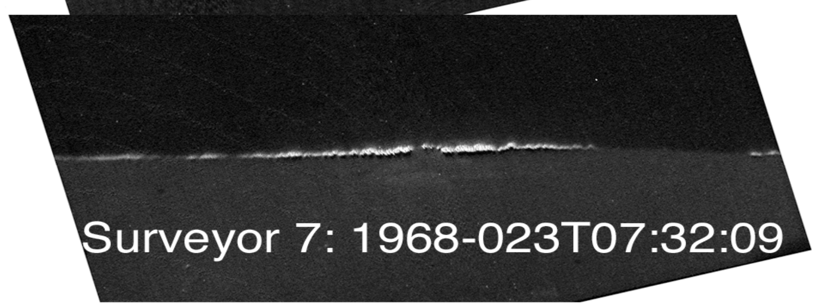

Surveyor 6: 1967-328T14:15:26


Surveyor 6: 1967-328T14:36:41

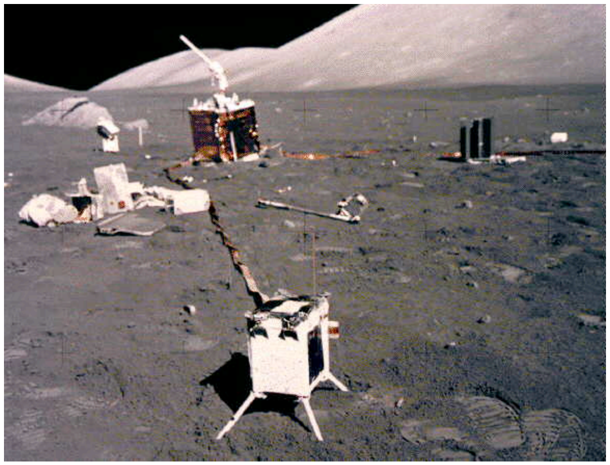

Surveyor 7: 1968-023T06:21:37


Surveyor 7: 1968-023T06:36:02

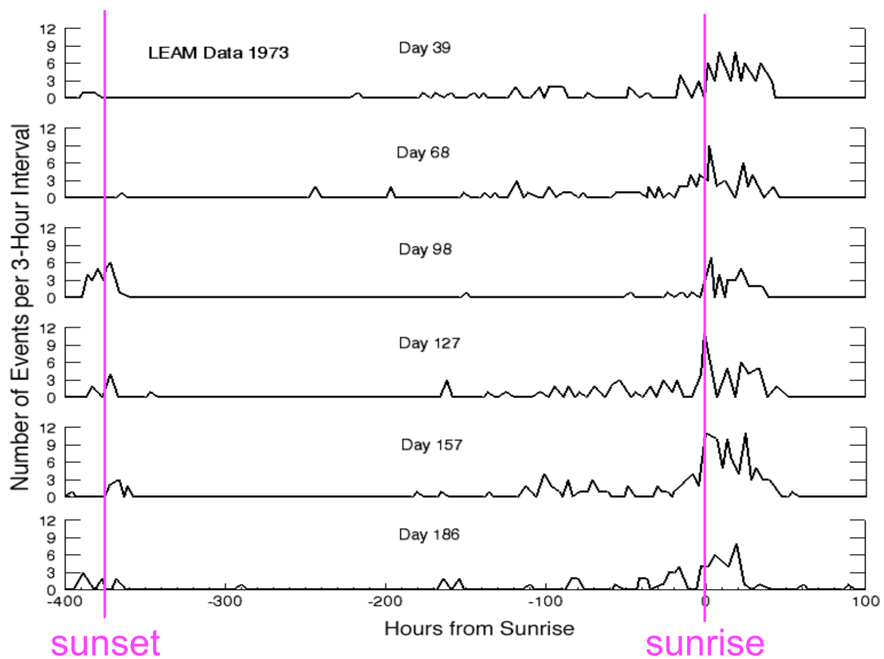

Surveyor 7: 1968-023T06:51:44

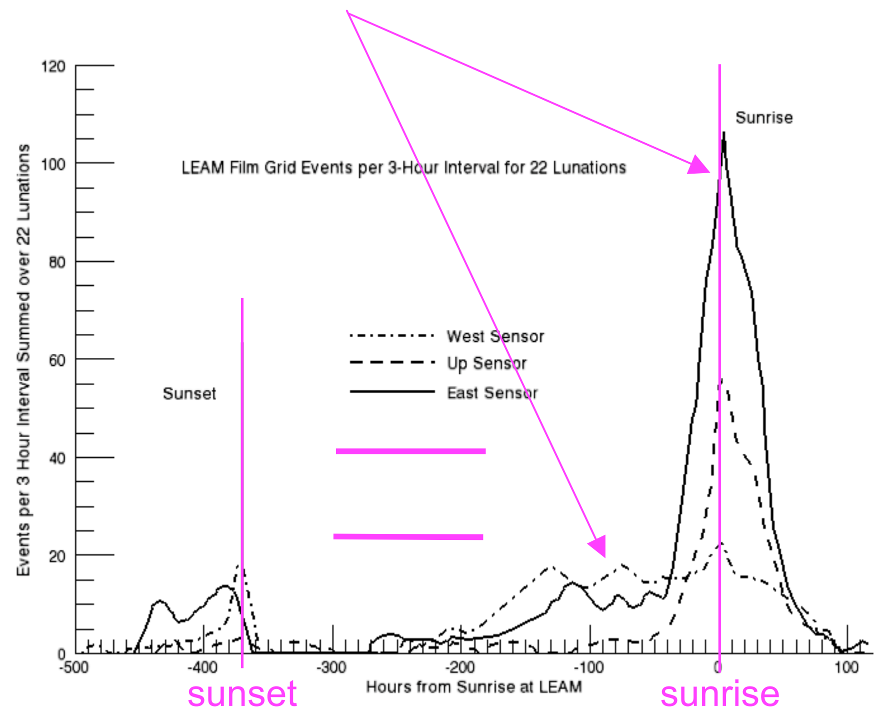

Surveyor 7: 1968-023T07:32:09

LEAM Apollo 17: Diurnal Lunar Dust "Weather"



Compare: Evidence for horizontal dust "wind"

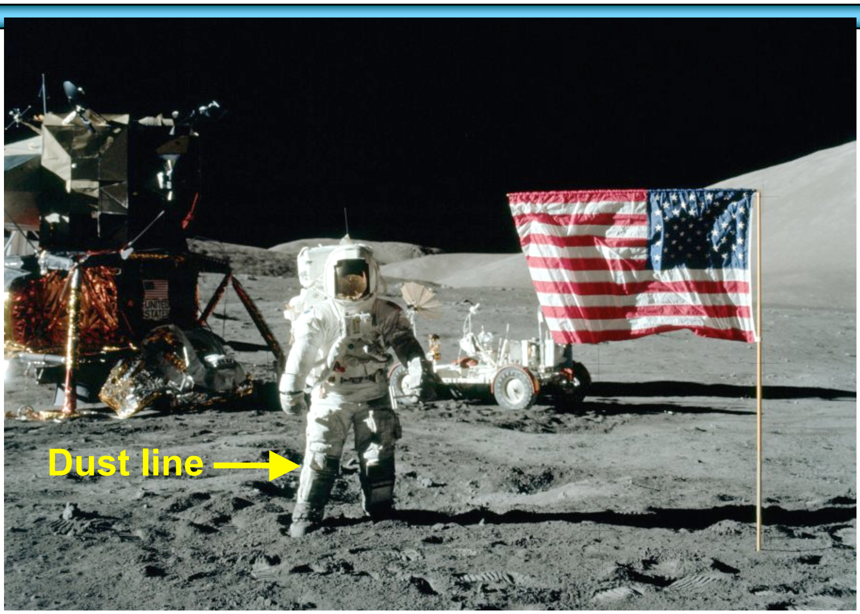


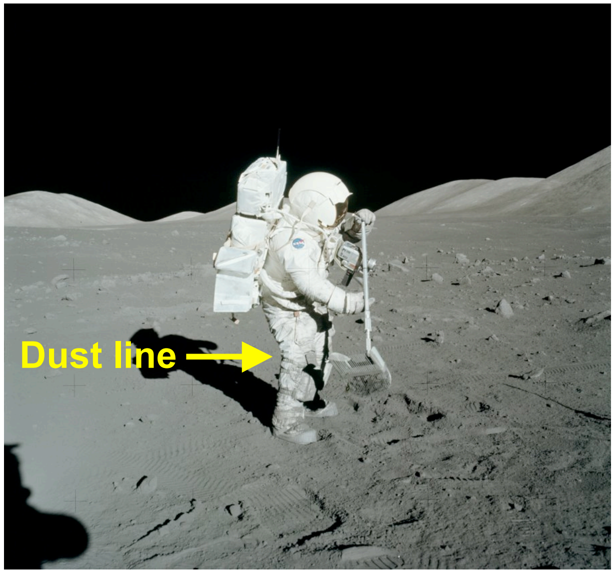


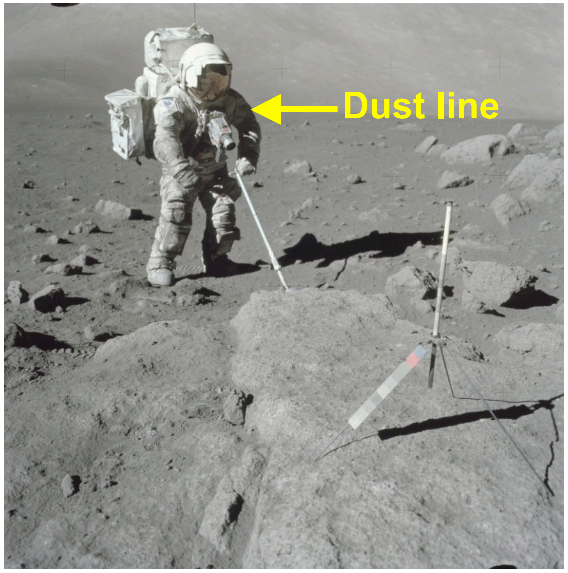
Persistent diurnal cycle in lofted dust density

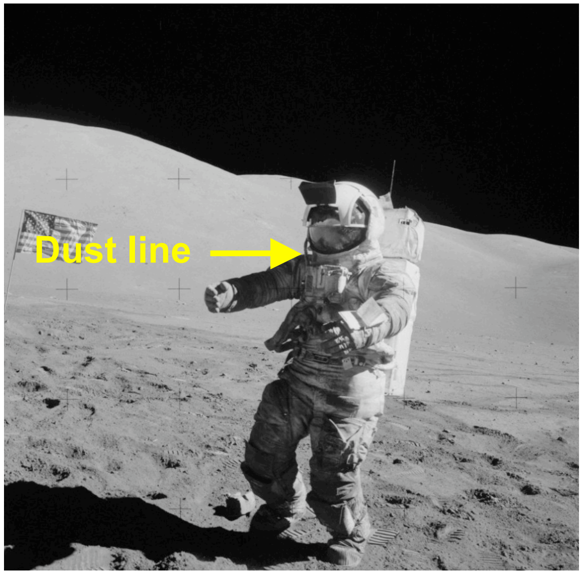
Lunar Dust and Human Activities

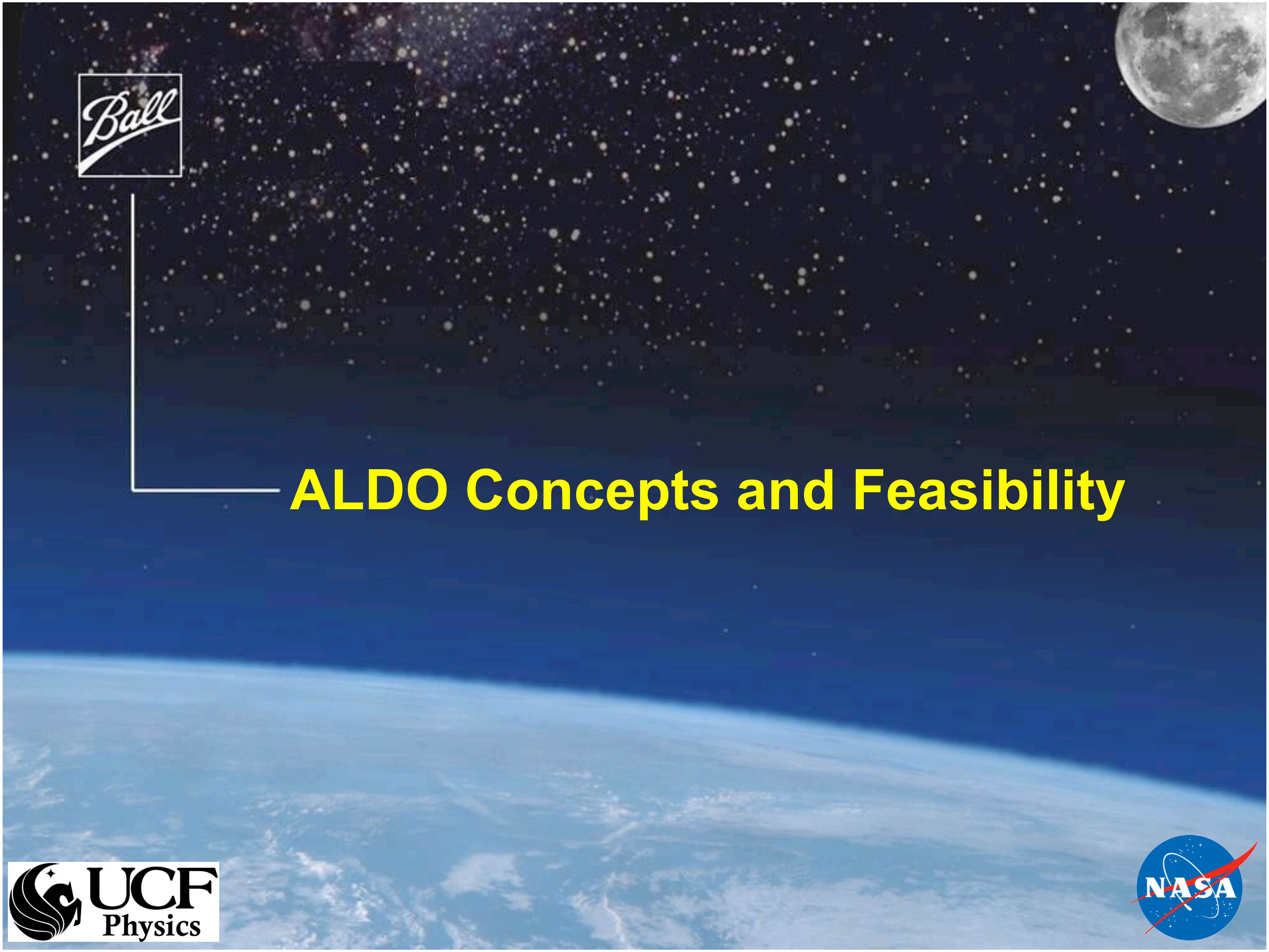
- Astronaut health
- Equipment performance
- Sortie site experiment disturbance
- Best experiment placement
- Impact on natural phenomena
- Determining best operating practices



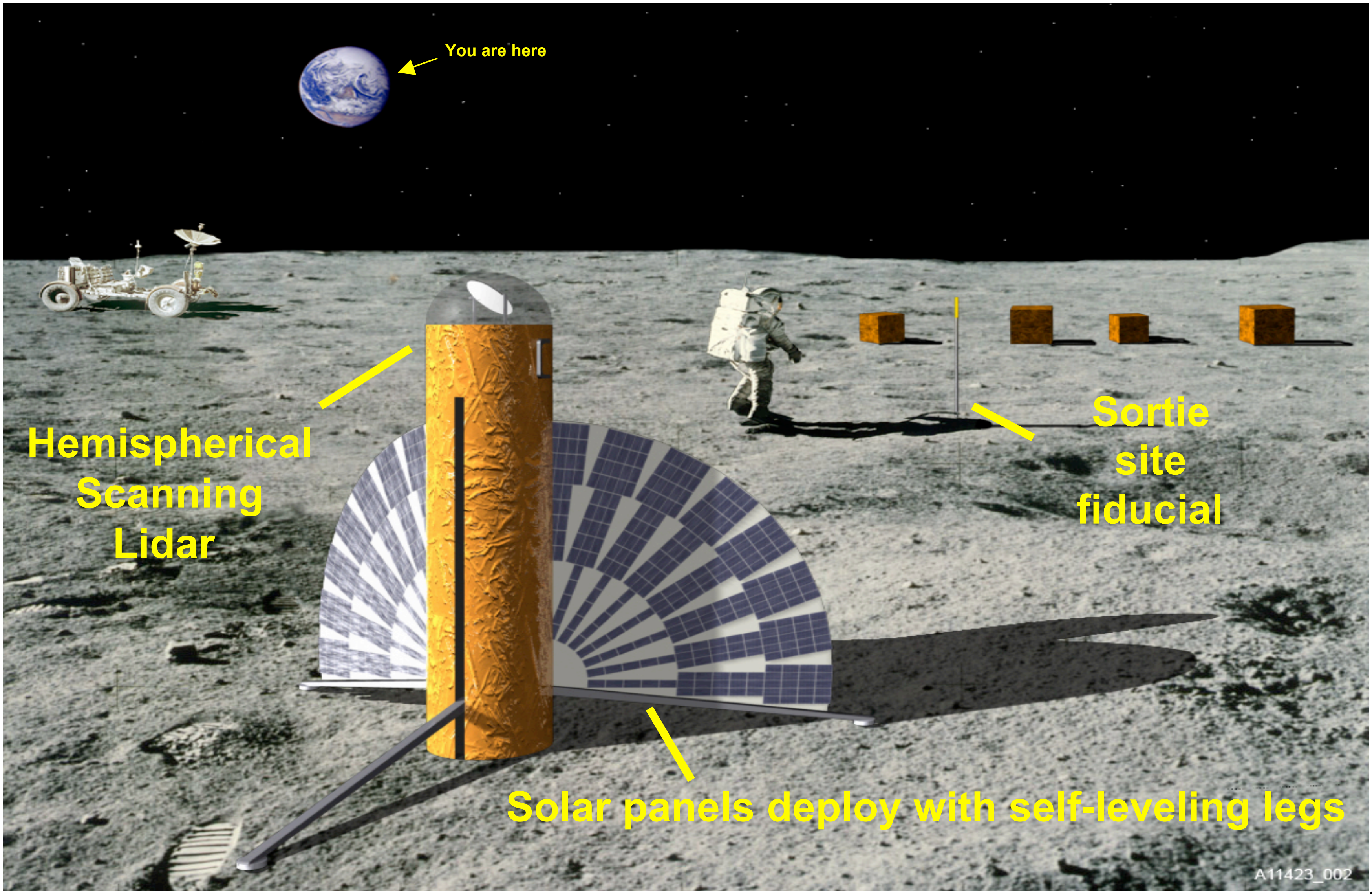




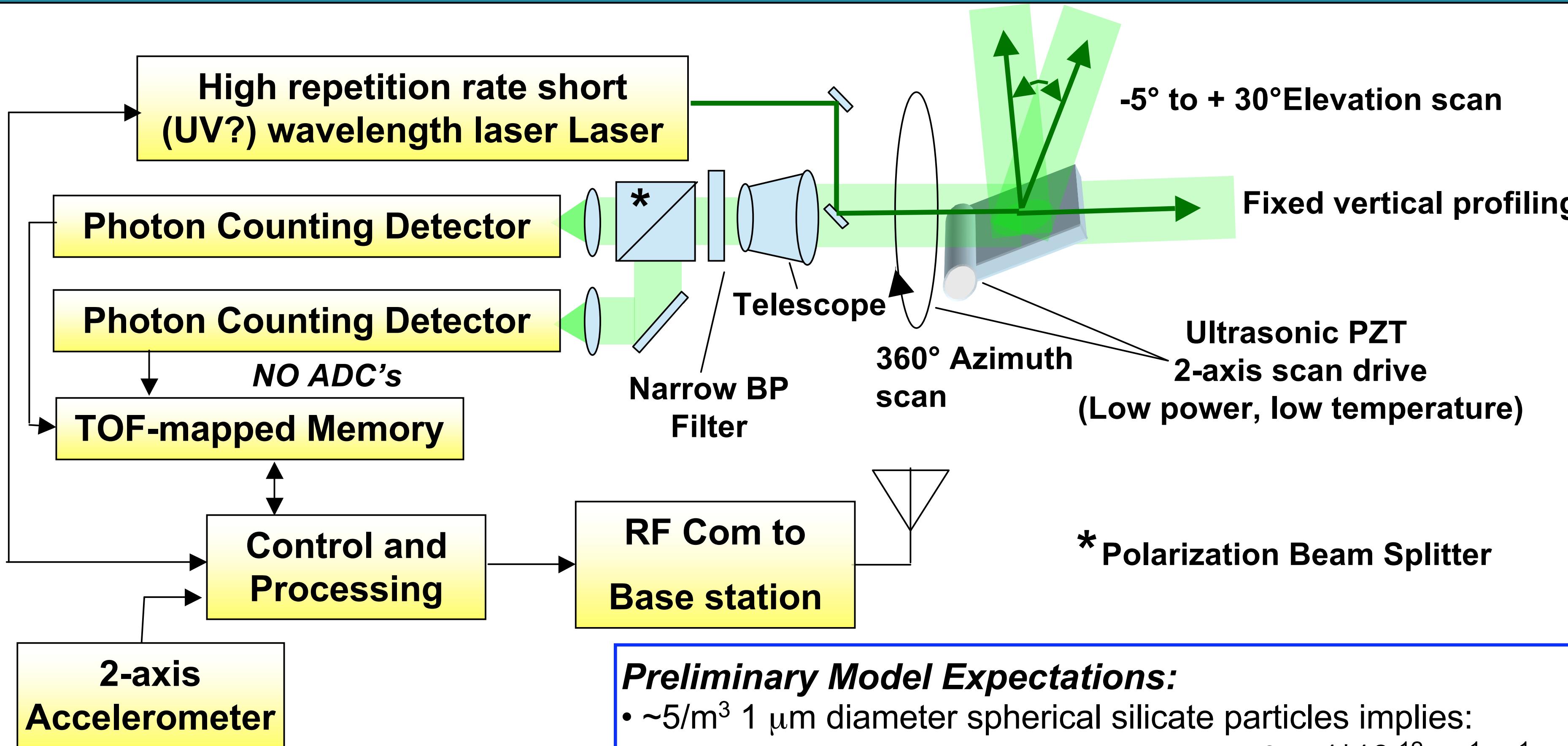



Ball
ALDO Concepts and Feasibility
UCF
Physics
NASA

ALDO Deployment Concept



ALDO Architecture



$$P(R) = P_0 * \xi * \frac{A_r}{R^2} * \frac{\Delta R}{2} * \frac{\lambda}{h*c} * \beta_\pi(R)$$

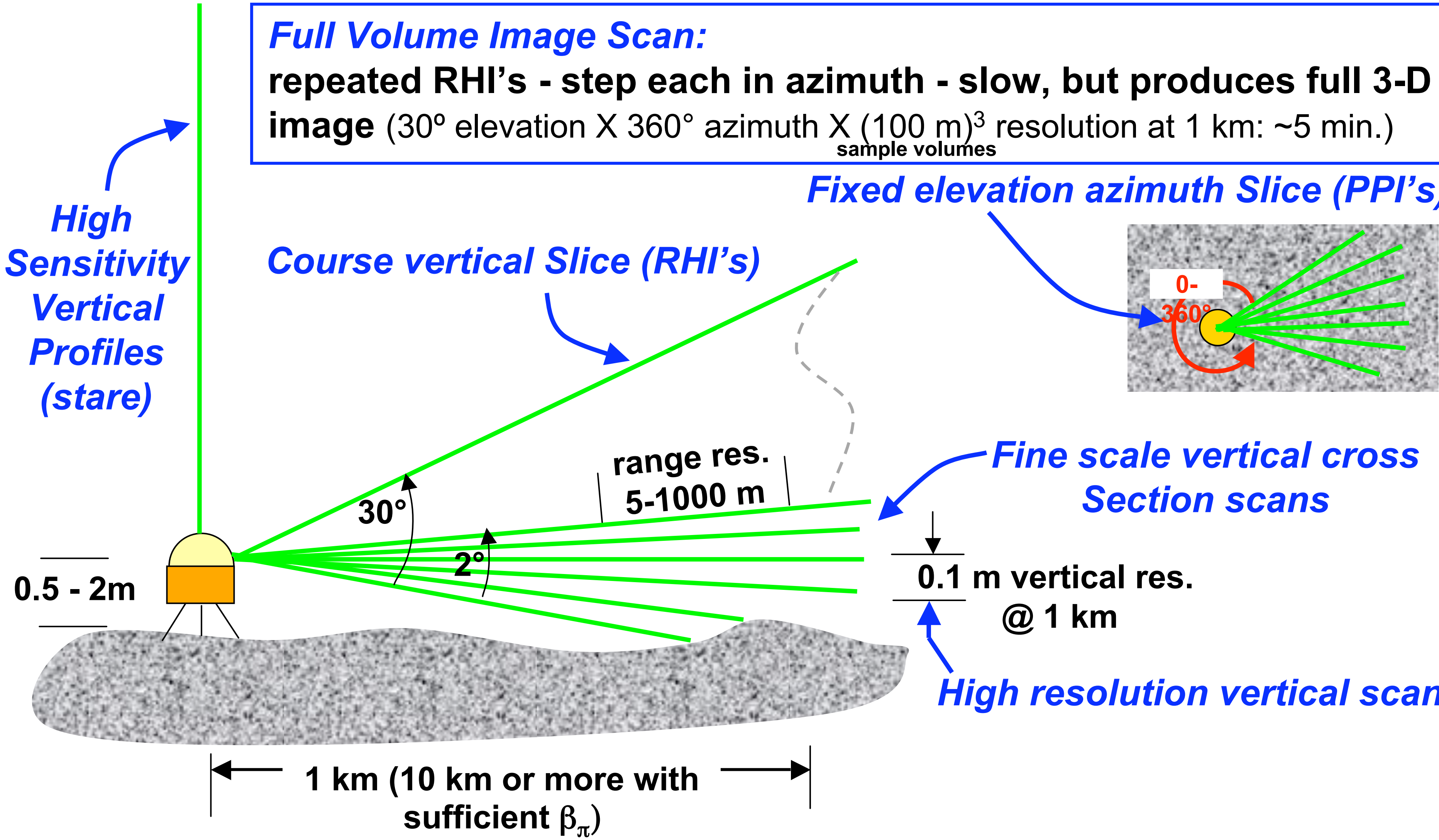
The lidar equation

Preliminary Model Expectations:

- ~5/m^3 1 μm diameter spherical silicate particles implies: β_π ~1*10^{-12} m^{-1}sr^{-1}
- ~2500 photon counts/s from 1 km range (~2% intensity)
- **1 W laser implies ~25 W average system electrical power**

ALDO Scan Modes

Full Volume Image Scan:
repeated RHI's - step each in azimuth - slow, but produces full 3-D image (30º elevation X 360° azimuth X (100 m)^3 resolution at 1 km: ~5 min.)
sample volumes



ALDO Modes and Motives

ALDO Operating Mode Concepts:

- Autonomous site survey using fiducial markers
- Self-calibration for intensity using fiducial marker signal returns
- Fine scale vertical profiling near surface
- Rapid 360° cross section scans that reveal and track coherent structures
- Panoramic volume images provide large scale dust context
- Long stares providing high sensitivity vertical profiles (perhaps to 10 km)

Systematic Process Studies:

- Lidar provides large area range-resolved dust observations without affecting plasma
- Micrometeorite impact plumes (rates, decay, transport)
- Natural phenomena – dark vs. sunlit, terminator crossings, fountains, profiles, dust transport and velocities (track coherent structures)
- Anthropogenic effects – what activities/methods kick up the most/least dust
- Decay time from disturbed to natural background state
- Instrument effects on the dust environment
- Supports studies of the solar wind, optical, and tribo- charging phenomena

Phenomenology Modeling

Numerical Simulations Predicting Dust

Motivation:

Predict the particle size and altitude distribution expectations for various to phenomena to evaluate ALDO requirements

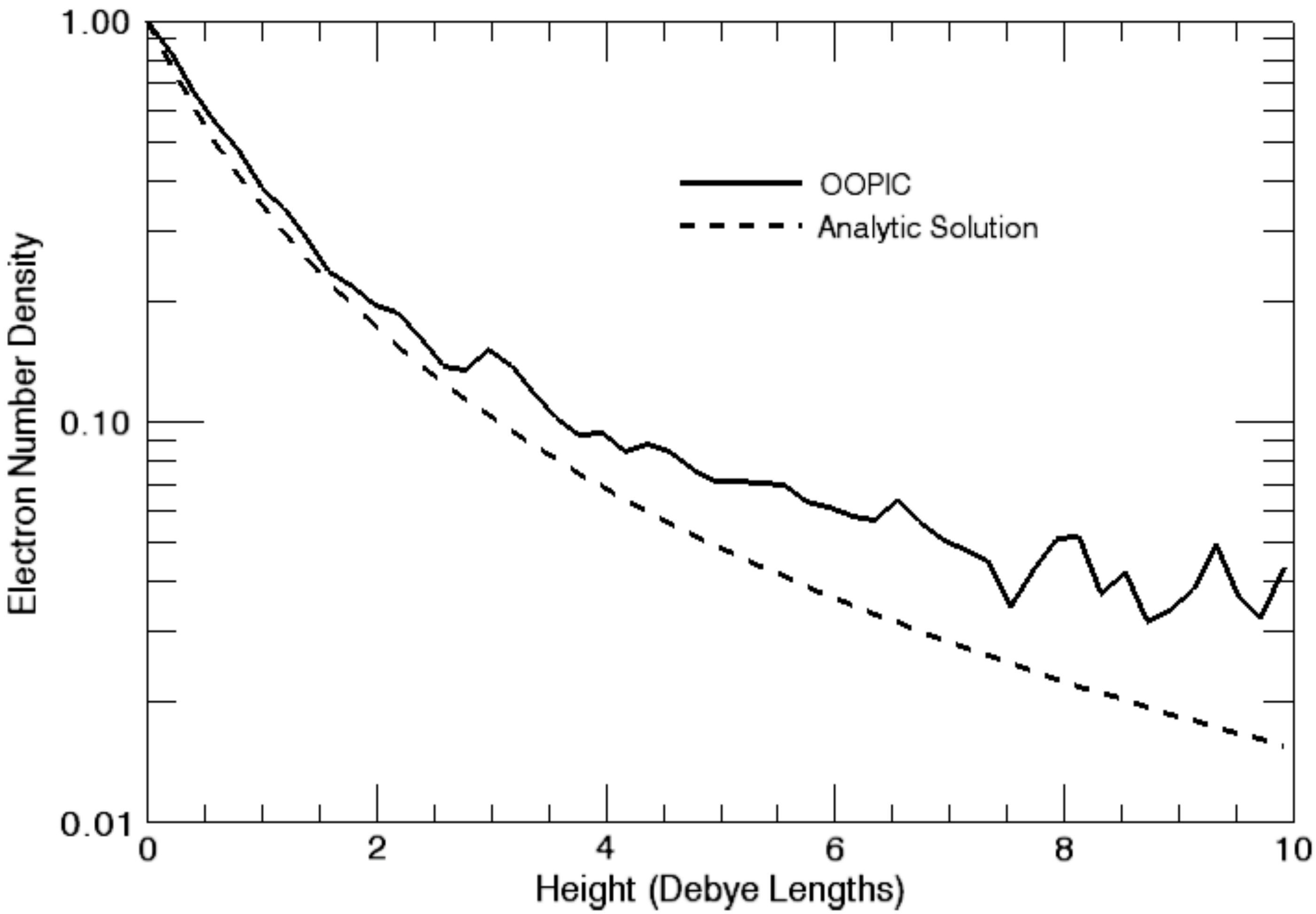
Model for Lunar Phenomenology and Particle Characterization:

- Dayside photoelectron sheath.
- Calculate surface potential.
- Calculate currents to dust particle.
- Integrate equation of motion under force of gravity and electric force.
- Include effects of topography on shadowing (surface potential) and trajectories (not yet included)

Assumptions in the Model for Lidar Backscatter:

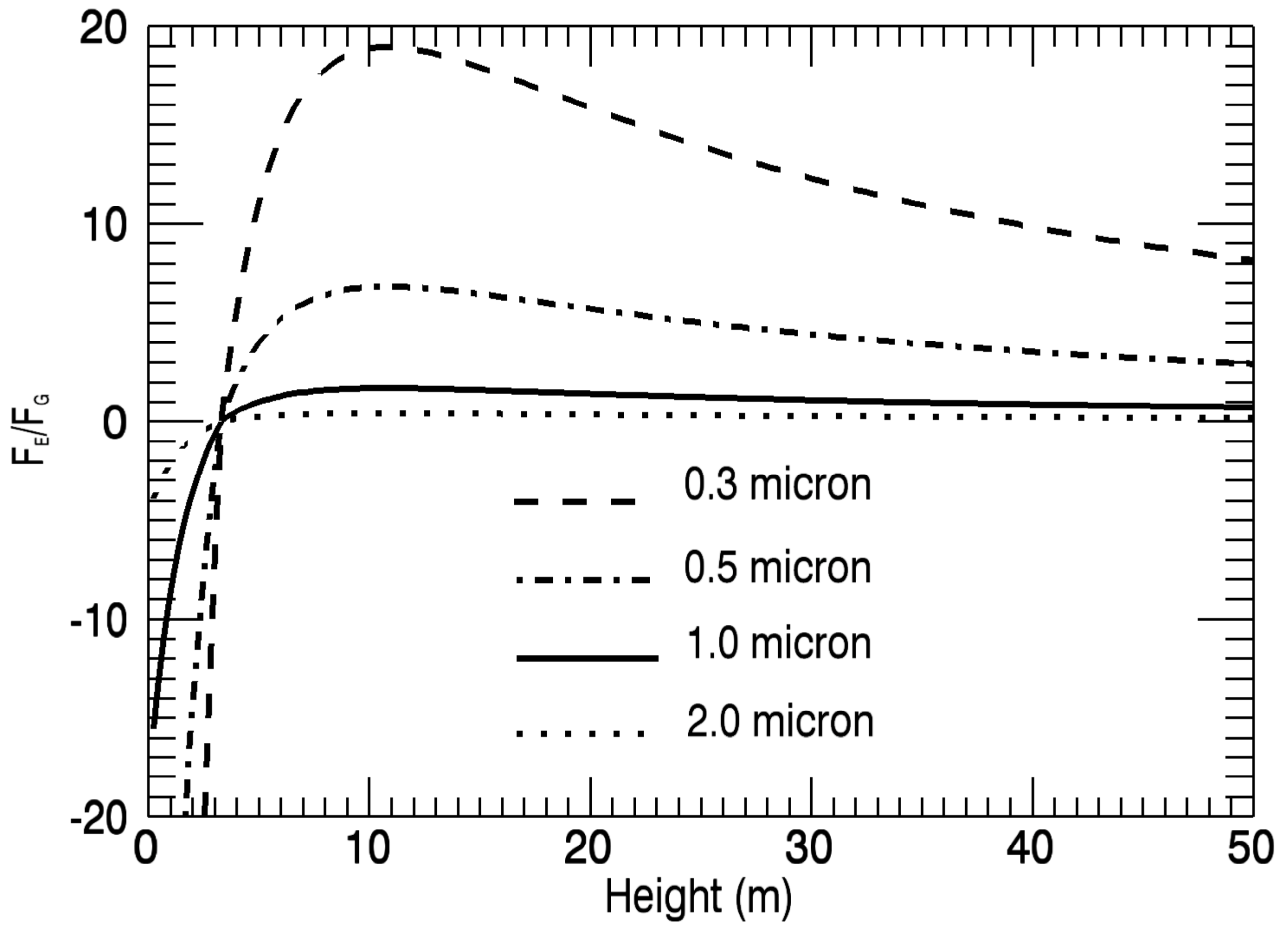
- Mie scattering (spheres) for now
- At the moment: flat *mass* distribution 100nm – 1000 nm

Object Oriented Particle in Cell (OOPIC) model simulation of plasma sheath

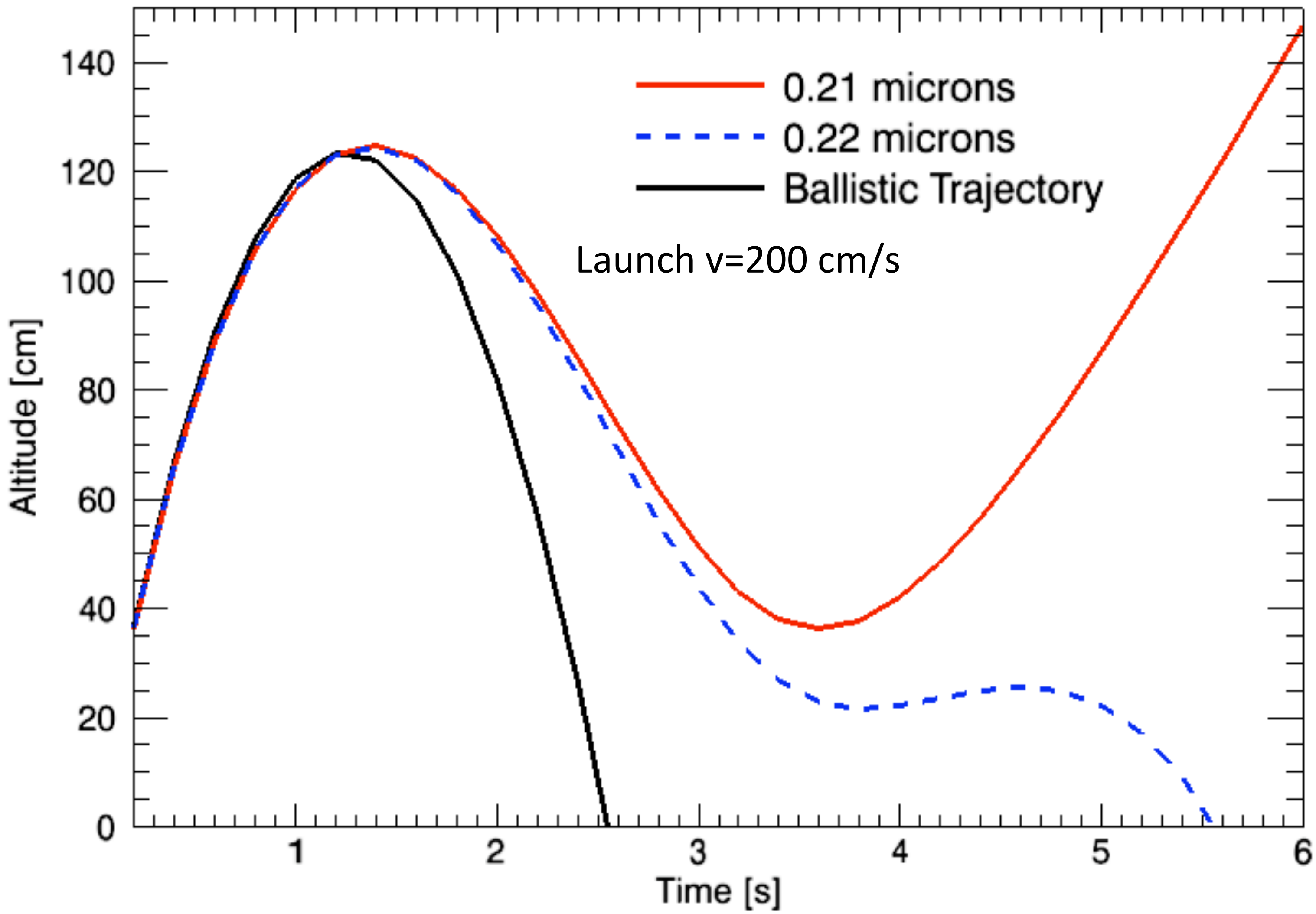


Colwell et al. 2009 (J. Aero. Eng., in press)

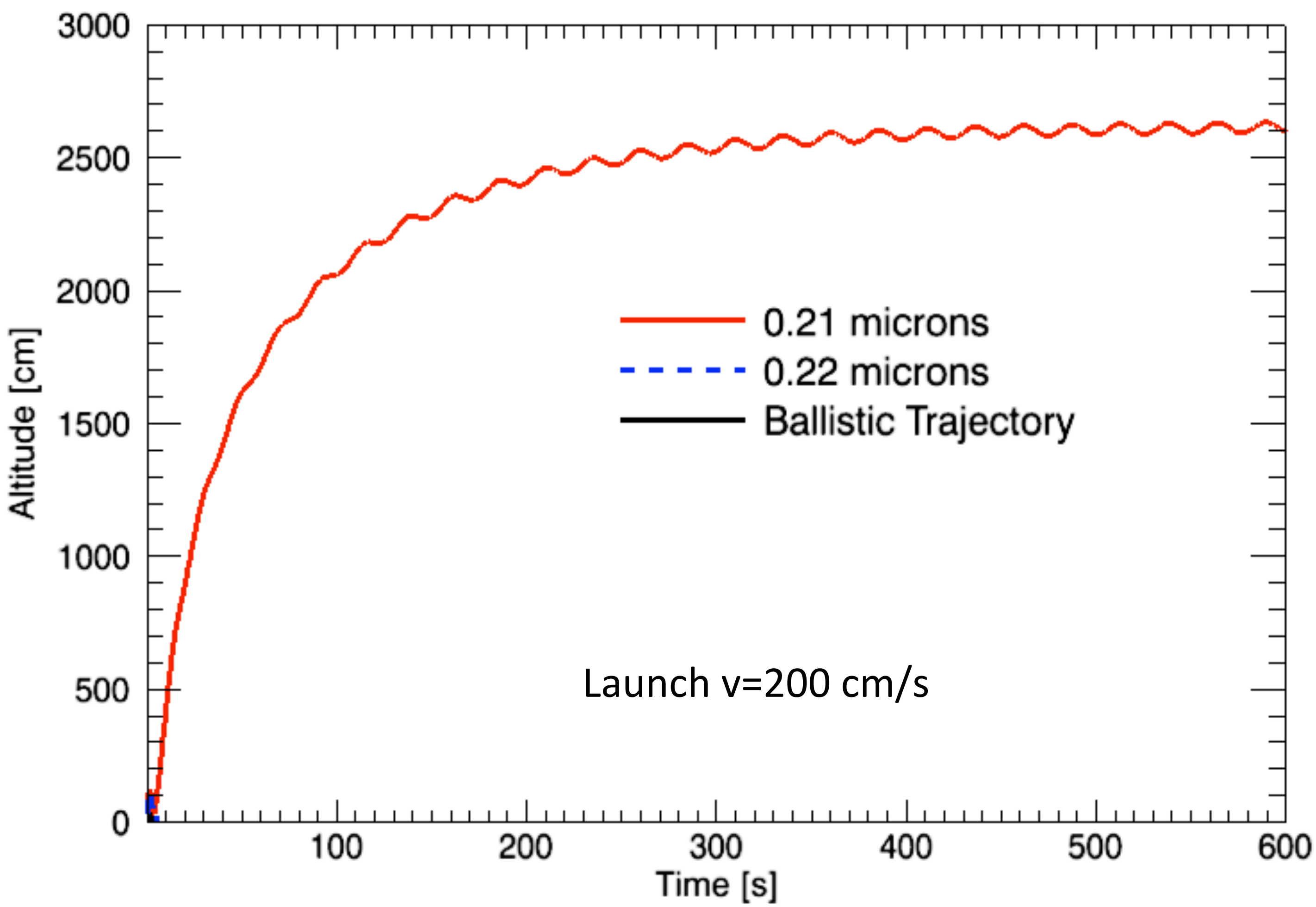
Electric vs. Gravitational Force Balance



Trajectories of Lunar Dust



Trajectories of Lunar Dust



Lunar Particulate Atmosphere Simulation Conclusions (so far)

- Surveyor Horizon Glow particles are not floating (would be much higher, extended cloud), but are on ballistic trajectories.
- Height of HG cloud and size of LEAM (~30 cm) limit likely electrostatic launch velocity to 1 m/s.
- Useful (and practical) to characterize particles in the range of 0.1 μm – 5 μm number density range TBD.

Next Steps

- Develop several standard dust atmosphere and performance predictions
- Hone in on laser and receiver requirements
- Trade power options (batteries, insulation, phase change materials)
- Consider night operations and survivability
- Consider ease of deployment
- Develop a technology roadmap

Conclusions

Observing natural and anthropogenic dust levitation and transport phenomena supports:

- **Study of the evolution of airless bodies (e.g. moon, NEOs) including formation of regolith, stratigraphy/compaction, water and other resource content, and albedo**
- **Health, safety, and operational efficiencies for extended human activities**
- **Optimal design of instrumentation for long term operation (thermal control, optical effects, power systems, mechanisms)**

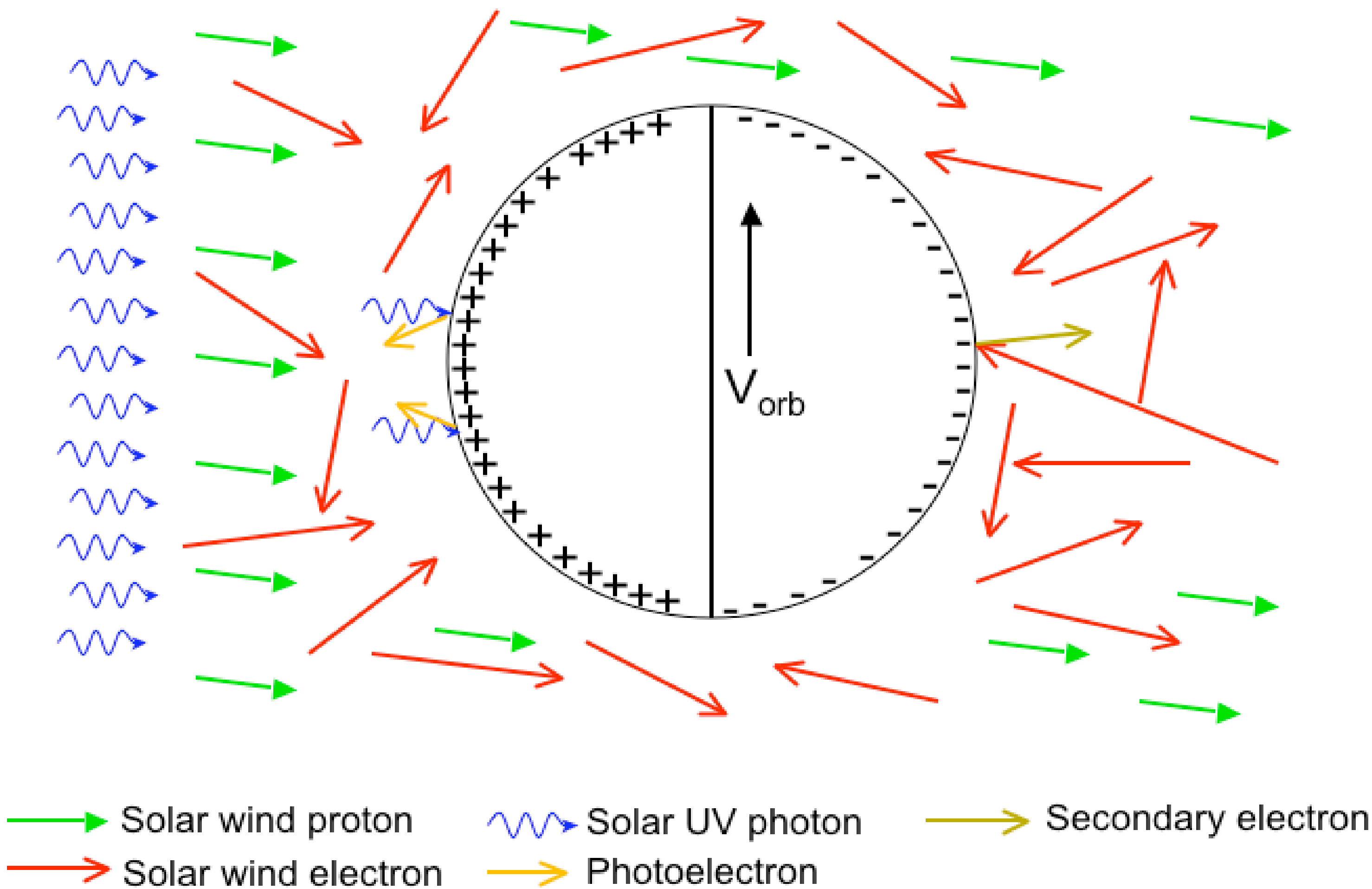
Systematic lidar profiling of the dust environment enables study of :

- **Micrometeorite impact plumes (rates, decay, transport, gardening)**
- **Natural background – dark vs. sunlit, terminator crossings, fountains, profiles, transport**
- **Anthropogenic effects – what activities/methods kick up the most/least dust**
- **Decay time from disturbed to natural background**
- **Instrument modifications to the local dust environment**
- **Solar wind, photoelectric, and tribo- charging effects on dust penomenology**

- ***A top level lidar concept has been developed using modeled expectations of backscatter***
  - ***Reasonable existing (but not qualified) UV lasers support photon counting measurements***
  - ***An easily deployed, compact, robust, scanning, dust profiling lidar appears feasible***

- ***ALDO is deployable on both robotic and human missions***

Backup: Charging of the Lunar Surface



Backup: Equations of Charge and Motion

$$dQ_d/dt = I_{pe} - I_e - I_{sw} \qquad \frac{d^2 z}{dt^2} = \frac{Q_d}{m_d} E - g \qquad E = 2\sqrt{2}\Phi_s \lambda_D \left(1 + \frac{z}{\sqrt{2}\lambda_D}\right)^{-1}$$

$\Phi_d < 0$

$$I_{sw} = \pi r_d^2 e n_{sw} \sqrt{\frac{8 k_B T_{sw}}{\pi m_e}} \exp\left(\frac{e\phi_d}{k_B T_{sw}}\right)$$

$$I_e = \pi r_d^2 e n_{pe} \sqrt{\frac{8 k_B T_{pe}}{\pi m_e}} \exp\left(\frac{e\phi_d}{k_B T_{pe}}\right)$$

$$I_{pe} = \pi r_d^2 e I_{ph0} \exp\left(\frac{-e\phi_d}{k_B T_{pe}}\right)$$

$\Phi_d > 0$

$$I_{sw} = \pi r_d^2 e n_{sw} \sqrt{\frac{8 k_B T_{sw}}{\pi m_e}} \left(1 + \frac{e\phi_d}{k_B T_{sw}}\right)$$

$$I_e = \pi r_d^2 e n_{pe} \sqrt{\frac{8 k_B T_{pe}}{\pi m_e}} \left(1 + \frac{e\phi_d}{k_B T_{pe}}\right)$$

$$I_{pe} = \pi r_d^2 e I_{ph0}$$